MANGING THE FUTURE NETWORK IMPACT OF THE ELECTRIFICATION OF HEAT

Stephen HARKIN
Delta-ee – UK
Stephen.harkin@delta-ee.com

Andrew TURTON
Delta-ee – UK
Andrew.turton@delta-ee.com

ABSTRACT

The partial electrification of residential heat using electric heat pumps is central to the UK's strategy for decarbonisation by 2050. Today, the penetration of heat pumps in the UK residential sector is low but is projected to grow significantly by 2050. This presents a significant challenge for the distribution network operators (DNOs) who may need to make major investments in their networks to facilitate this increased electricity demand. Delta-ee carried out a study for Electricity North West (ENWL) (a UK DNO) examining the potential impact of heat pumps on its distribution network, and mitigation options including demand side measures, storage, and efficiency improvements to reduce reinforcement costs.

BACKGROUND AND AIMS

In the UK today, the penetration of heat pumps (HPs) in the residential sector is low, accounting for less than 0.5% of the installed base of residential scale heating appliances, and around 1% of annual heating appliance sales. However, by 2050, a range of scenarios forecast that millions of HPs could be installed in residential homes. For example, National Grid's 'Gone Green' scenario suggests there could be ~9 million domestic scale HPs (electric & hybrid) installed in the UK by 2040. The Committee on Climate Change has a number of scenarios for HP uptake by 2030 ranging from ~2 million to almost 14 million.

This could result in significant additional electricity demand for the electricity system, and could add significant electricity demand at peak times, requiring major, and costly, reinforcement of the electricity distribution networks.

Looking ahead to 2030 and beyond, Electricity North West (ENWL), a UK DNO, identified that residential electric heating could be a major addition to peak load and investment requirements on its network. It also identified that electric heat (via HPs) presents major uncertainty in how peak load would grow. Domestic HPs have often been characterised as one homogenous group, ignoring variety in heat demand by house type, changes in how HPs will be operated in future, and how their operation could be influenced by suppliers or system operators. There is anecdotal evidence that system operator requirements from electric heating could conflict with DNO requirements, and therefore the latter point is of particular interest.

ENWL carried out a study with Delta-ee to help resolve the uncertainty so it could develop its network and its services to meet future customer needs. This study on electric heat fed into a wider Network Innovation Allowance (NIA) project called 'Demand Scenarios with Electric Heat and Commercial Capacity Options'.

The NIA project has two key aims. Firstly it develops improved peak load scenarios by substation (not just reflecting changes in electric heat, but also summer air conditioning, and underlying demographic, economic, and energy efficiency changes). Secondly, the improved load scenarios are then used to assess commercial options to delivering capacity on ENWL's network, such as post-fault demand-side-response.

Delta-ee's role within the NIA project (which is the focus of this paper) was to develop new granular & robust load profiles for different types of HPs in different house types, understand how these load profiles would vary on different winter days (average versus extreme), identify the scale of impact future uptake of the HPs on ENWL's network, and to explore the impact that other stakeholders influencing the operation of HPs could have on ENWL's network.

Understanding the scale of the potential impact that HP uptake will have on distribution networks is complex, and will be influenced by:

- The **total number** of HPs deployed
- The **types** of HPs installed (air source (ASHP), ground source (GSHP), and hybrid)
- The **types of dwellings** that the HPs are installed in – which affects the load profile & operation of the HP
- The **capacity** of the HPs installed
- The **location** of the HPs and the clustering of their deployment – a high concentration of HPs in an already constrained part of the network may require reinforcement
- The **weather conditions** – the efficiency of HPs falls as the temperature of the heat source (air / ground) falls, meaning electricity load will be highest on the coldest days
- The **coincidence of HP operation** – not all HPs will be switched on at the same time, or will be operated in the same way by home owners.
- The **control / operation** of the HPs – which could shift more demand to peak times.

This complexity makes it highly challenging for network companies to plan for and manage the impact of HP uptake on their networks.

METHODS

In order to quantify and characterize the impact of HP uptake on ENWL's distribution network, and number of steps were taken:

Step 1: Gathering existing data insights on real life HP operation

This involved collating data already gathered on HP load profiles and real life performance from UK and European trials, as well as gathering HP performance data and system architecture inputs from manufacturers and installers.

Step 2: Building physics modelling to develop new robust HP load profiles for different house types, on average and extreme winter days

Delta-ee utilised a building physics model to simulate the operation of different types of HPs in different house types, and generated half-hourly load profiles for HPs operating in dwellings typical of ENWL's region.

The following types of HPs have been considered:

- Higher temperature ASHP – an electric air-source HP that generates flow temperatures up to 80°C
- Lower temperature ASHP - an electric air-source HP that generates flow temperatures up to 40 - 50°C
- Hybrid HP – a system which combines an electric air-source HP & a gas boiler
- Ground source HP

The approach of using a building physics model to simulate HP operation was required to be able to consider the operation of different types of HPs, in different house types, on an average peak winter day and an extreme ('1 in 20') peak winter day. This granularity was important for the study, and measured real life data from trials at this level of granularity did not exist.

This approach also enabled the many factors that influence the efficiency of HPs to be considered – which is key to understanding the impact HPs will have on the electricity network in the future.

The key factors that influence HP operation, which were considered in the modelling are:

Temperature lift:
Temperature lift is dependent on the variation in outdoor temperature through the year, and on the variation in flow temperature that is required to heat a building. This is the most significant factor influencing HP efficiency. As the outdoor temperature cannot be influenced, the flow temperature is therefore the main vector to improve a HP's performance. We have therefore modelled different buildings which use higher or lower flow temperatures, in order to reflect the high variance in installations that can be expected in the field.

Technical efficiency and control strategy:
Performance of HPs varies between models and installations. The control strategy can help to reduce the temperature lift, by foreseeing weather compensation, as well as through reducing the need for cycling the HP.

Building type / suitability:
The level of insulation and types of heat emitters (underfloor, radiators) influence the flow temperature required to heat a dwelling on the coldest days of the year. HPs perform best in well-insulated buildings with underfloor heating (low flow temps), and poorest in non-insulated buildings with radiators (high flow temps).

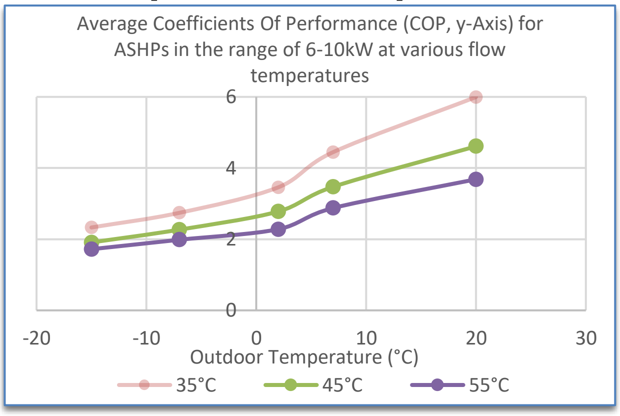
Sizing and design:
The sizing of the HP and the design of the installation can impact the overall performance of a system. For example, HPs which have too small a capacity for their building will need to run at higher temperatures (or use more back up electric heating) to meet the building's heat demand.

Commissioning:
The correct commissioning of the HP is an important factor for the HP's efficiency. Optimising the heating curve, domestic hot water temperature and legionella prevention cycles for the needs of the building and user can be crucial for the performance of the system.

Temperature settings and domestic hot water use:
The user behaviour can influence the HP performance. Higher room temperatures e.g. require higher flow temperatures to reach them.

Due to the many parameters which can influence the performance of a HP in a building, six different combinations of buildings and HPs have been modelled to generate a variety of load profiles for HPs in ENWL's distribution area. The efficiency data used in the study is based on averaged COP data from a number of HP models from companies selling in the UK, as depicted in figure 1.

Figure 1: Average efficiencies of ASHPs at different outside air temperatures and flow temperatures.



Step 3: Diversification of HP load profiles

Not all heat pumps will be operating in the same way, at the same time – this is an important consideration when understanding the future impact of HPs on the electricity network. For example some homes may not be occupied on a particular evening when a heating system would otherwise be switched on (e.g. holidays), or some homes may switch their heating system on earlier (or later) than in other homes depending on work patterns.

Therefore, when considering the impact of HP uptake on the network, it is important to consider the 'diversified' load profile of the **population of HPs,** which includes the impact of variations in operation times and modes. Without diversifying the HP operation, it is likely that the coincidence of peak demands will over-estimate the impact on the distribution network, and could result in unnecessary network investments.

No existing data was available on the diversified operation of HPs so Delta-ee developed a diversification approach, taking into account the following key factors:

- Occupancy levels of dwellings (i.e. how many homes will be occupied at any one time, at different times of the day).
- Unimodal (single heating period per day) versus bimodal (two heating periods per day) heating system operation.
- The timing at which homes will want to be warm.
- The volume of HPs over which diversification needs to occur – i.e. are we considering 10s of installations (such as at the DNO level) or 100,000s of installations (such as at the national level).

Step 4: Forecasting uptake of different types of HPs in ENWL's region.

Delta-ee developed three scenarios for HP uptake on ENWL's network to 2050, using the Delta-ee Pathways methodology. The three scenarios considered provided a wide range in the level of uptake by 2050, enabling ENWL to understand how sensitive its existing network infrastructure is to varying levels of HP penetration.

The three scenarios considered are:

- Scenario 1: The 'Delta-ee reference scenario' – a reference forecast for HP uptake, which represents what Delta-ee believes **will** happen in reality based on current market evidence.
- Scenario 2: The 'high' scenario. This scenario is aligned with the Transform model interpretation of DECC's (now BEIS) national high heat pump uptake rate, referred to as the 'DECC 1' scenario.
- Scenario 3: The 'low' scenario. This scenario is aligned with the Transform model interpretation of DECC's national low heat pump uptake rate, referred to as the 'DECC 4' scenario.

Each scenario was built up around the four pillars:

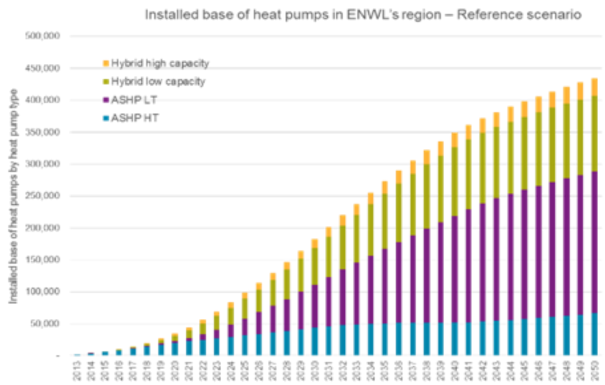
- Policy and regulatory framework
- Technology development (performance & cost)
- Customer & installer attitudes and awareness
- Industry push from manufacturers & government.

Across the three scenarios, the total uptake of HPs varied, as did the mix of HP types being deployed. Table 1 illustrates the total number of HPs deployed in ENWL's area by 2050, and figure 2 illustrates the installed base of HPs to 2050 under the reference scenario.

Table 1: Heat pump uptake under the three scenarios

Scenario	Installed base of heat pumps in 2050	Share of dwellings with a heat pump in 2050
Low	127,570	~ 5%
Reference	434,479	~20%
High	1,158,115	~50%

Figure 2: Evolution of the installed base of HPs in ENWL's region under the reference scenario.



Step 5: Analysis of HP operation and modelling the impact on ENWL's network to 2050.

The growth in HP uptake provides DNOs the opportunity to distribute more electricity, invest more in the network and generate more revenue. However, the timing of this new demand could overlap with existing 'peak load' times, presenting new challenges to DNOs in terms of the capacity requirements of the network.

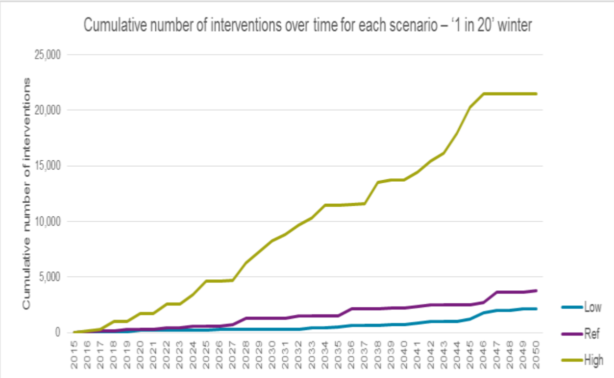
Adding to this, other players in the electricity value chain (e.g. electricity suppliers and the system operator) may also begin to influence the operation of electric heating & heat pumps to optimise the operation of the wider electricity system (e.g. influencing electricity demand to maximise the use of low cost electricity). This 'optimisation' will be based on national, rather than local, price signals, and optimising at this system level could actually increase the stresses that HP load causes at the DNO level (e.g. if price signals shift / encourage heat pump load to increase at peak load times), making the challenge for ENWL even higher.

A key part of the study was therefore to assess the impact that 'optimised' heat pump load profiles will have on ENWL's network.

Delta-ee worked with Imperial College and its ASUC model to modify the load profiles of heat pumps in order to 'optimise' the energy system in 2050 (to run at lowest cost). This 'optimisation' of HP operation for the benefit of the wider energy system resulted in more load being shifted to peak times of operation – which makes the impact of HP uptake even greater for network operators.

Then, using the EA Technology's TRANSFORM model, Delta-ee was able to quantify the level of investment required by ENWL to upgrade the network to support the forecasted uptake of heat pumps by 2050 – utilizing the non-optimised and optimised heat pump load profiles, as shown in figure 3.

Figure 3: Cumulative number of network interventions over time.



Step 6: Consideration of customer side measures to reduce and manage the network impact of HPs.

A number of 'customer side measures' were considered that ENWL could implement to minimise and influence the impact of heat pump uptake on its network.

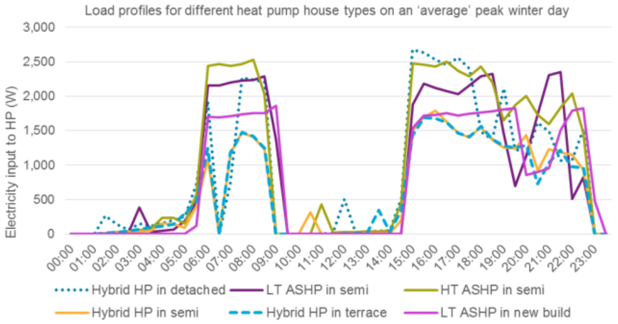
For each measure, HP load profiles were modified / new load profiles were simulated to reflect the introduction of these measures, before simulating the impact of these measures on ENWL's network in the Transform model.

RESULTS

Modelling the operation of different HP types, in a number of dwellings (on different winter days and under different uptake / optimisation scenarios), has enabled the assessment of peak electricity demands on ENWL's low voltage distribution network to 2050.

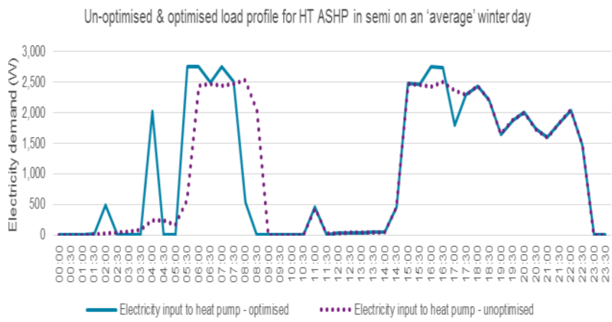
By using the new HP load profiles generated from this modelling (illustrated in figure 4) in the TRANSFORM model, the number of network 'interventions' required to facilitate HP uptake and the associated investment costs required by 2050 could be better understood.

Figure 4: Load profiles for 6 different HP – house type combinations on an 'average' peak winter day.



Heat pump optimisation analysis demonstrated that shifting the thermal loads and heat pump operation in line with system level optimisation could actually increase the peak load (in the order of 5 – 10% as illustrated in figure 5 below), shifting more demand into peak periods, and increasing the number of network interventions required by 2050 by 20 – 70%, equivalent to £100 - £200 million.

Figure 5: 'Optimised' vs non-optimised load profile for a higher temperature ASHP in a semi-detached dwelling.



The modelling demonstrated the load from all HPs deployed on ENWL's network in 2050 will peak at 0.25 GW – 3.5 GW (table 2) depending on outside temperature, the mix of HPs, and the HP uptake rate. The upper end of this range is more than 50% of ENWL's peak load today.

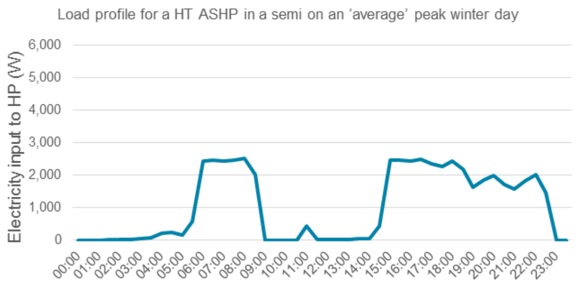
Table 2: Additional network loads under each scenario

Scenario	Share of homes with HP	Additional network load on average winter peak	Additional network load on a '1 in 20' winter peak
Low	~5%	200 – 300 MW	400 – 500 MW
Reference	~20%	800 – 900 MW	1,400 – 1,500 MW
High	~50%	~2,500 MW	~3,500 MW

On an 'average' peak winter day, a residential ASHP adds up to 2.5 kW per dwelling, but this increases to 5.5 kW per dwelling on a '1 in 20' peak winter day due to the use of a supplementary direct electric heater. With diversification of HP operation, this additional load of remains significant. Our diversification approach resulted in peak load typically reducing by 5 – 10% depending on the HP – house type combination, and the winter day considered.

This means that assuming a current 'after diversity maximum demand' (ADMD) of 1.5 kW per house, heat pumps could increase demand at peak times by ~2 – 4 times per dwelling, placing significant stress on the electricity network and requiring extensive reinforcement calculated at between £150million and £3.3billion. The load profiles in figure 6 demonstrate the significant impact that colder conditions can have on peak network loads, and table 3 shows the number of interventions and reinforcement costs for the reference scenario.

Figure 6: ASHP load profiles for an average, and 1-in-20 winter peak.



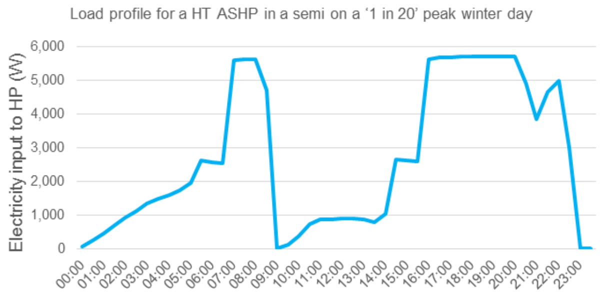


Table 3: Number and cost of interventions by end of each time period (reference scenario).

	2022	2030	2050
Cumulative number of interventions required by end of time period	439	1,320	3,808
Cumulative costs associated with LV ground mounted upgrades (£ millions)	6.0	9.8	35.7
Cumulative costs associated with LV underground minor works (£ millions)	15.0	111.5	303.5
Total cost (£ millions)	**21.0**	**121.3**	**339.2**

The DNO could take a range of measures to mitigate the increased peak loads from HPs by working with customers. For example, ENWL could work with customers to influence measures such as reducing heating demands with efficiency improvements (e.g. insulation), incentivising installation of more efficient HPs (or larger capacity HPs – to avoid use of back up electric heating), promoting different control and storage strategies, or using distribution pricing structures to limit adverse impacts from other parties.

Modelling the impact of these measures on the HP load profiles shows that the potential avoided network costs of these measures (aimed at heating only) for the reference scenario could be up to £200 – 300 million, and more than £3 billion by 2050 for the high scenario. Table 4 summarises the scale of the avoid network costs in 2050 that may be realised by deployment of certain measures.

Table 4: Avoid network costs from deployment of customer side measures, reference scenario, average peak winter day.

Measure	Avoid cost by 2050
increasing insulation levels of all dwellings	£73 million
installing higher capacity HPs	£65 million
installing higher efficiency HPs	£1 million
incentivise hybrid uptake rather than ASHPs	£ 220 million
Micro CHP installed alongside HPs	£ 6 million
Shifting HP operation with control strategies	£ 220 million
Battery storage installed alongside HPs	£ 220 million

There will be additional costs incurred by deploying these measures which could exceed the benefits, rendering them un-economic. Some of these additional costs may be borne entirely by ENWL while other measures may be supported via national programmes – reducing the direct cost to network operators.

CONCLUSIONS

This study provides a detailed assessment of the impact of heat electrification on ENWL's distribution network. It takes into account the range of HP technologies for different customer types, the potential variation in operation, including the impact of system level optimisation, and the variation in technology performance due to average and extreme winter weather conditions.

The results demonstrate that heat electrification could have a major impact on the distribution networks, with peak loads per dwelling increasing by 2 – 4 times, and additional peak loads of up to 5.5 kW per dwelling connection. The impact of system level optimisation could contribute to this increase by shifting loads to peak heating times, and be detrimental to the distribution network. Taking into account the expected uptake of HPs, additional network investment of ~£340million will be required by 2050, increasing to over £3 billion under a high uptake scenario.

ENWL is unlikely to have much control over the uptake of HPs and their operation, but they could influence a number of customer-side measures to reduce the increases in peak load from heat electrification. These could significantly reduce additional network reinforcement investment, but may be expensive to introduce. In the high scenario for example, improving the insulation levels of all dwellings installing a HP could reduce network investment costs to 2050 by ~£600 million (costing around £570 million to implement).